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ABSTRACT. Given the rising costs of energy and the tight supply of key fuels, climate variations can have a major impact on society by affecting energy production and demand. The winter of 1976-77 brought continued drought to the western United States and cold weather to the eastern United States. This lifted U.S. energy demand for fossil fuels by the equivalent of 200 million barrels of oil. The weather pattern for that winter was an extreme version of a common pattern that is associated with colder than normal temperatures for most of the heavily populated north temperate zone. If such an extreme climate event had occurred during the winter of 1979-80, it would have increased the world oil shortfall by several percent making a bad situation worse. An international effort would be needed to determine the frequency and nature of such extreme climate variations, and to discover if these events are predictable. Monitoring of global temperature and precipitation data could provide early warning that world-wide energy consumption is unusually high. Use of such information could help ameliorate the impact of an extreme climate event on the global economy.

RECENT CHANGES IN ENERGY ECONOMICS

As little as ten years ago crude oil was cheap and appeared abundant. Rapid growth in energy consumption has put the world in a position where supply and demand for oil are precariously balanced (1). Twice in the last seven years events in the Middle East have resulted in slight shortfalls in energy supply. These minor shortfalls have permitted a catastrophic rise in the price of a barrel of oil from \$2 to \$30. Even as the present crises abates, decisions by major producing countries not to rapidly increase (or even to decrease) production mean that further supply disruptions and attendent price increases are likely.

Given tight supplies and the resulting high prices, climate variations can have a major impact on society. An unusually cold winter can raise heating bills beyond the ability of some people to pay. Domestic energy production can be severely disrupted. Frozen rivers impede the barge transportation of coal. Unusually cold weather can stress mechanical systems such as natural gas pumping facilities past their design limits resulting in curtailments of delivery. Power production can be reduced when freezing weather solidifies piles of coal. Severe weather conditions can also substantially impede oil production, particularly offshore. Drought can significantly diminish the supply of hydroelectric power and increase the use of fossil fuels for pumping irrigation water. Production reductions coupled with increased demand will result in increased oil imports. This will weaken the national currency. Extreme climate events can even cause large enough energy shortfalls to result in widespread unemployment.

This paper will describe the impacts that climate anamolies have had on energy systems in the United States, and the resulting impacts on society. It will also point out how better use of climate information could alleviate some of the adverse consequences of these anomalies. Finally, it will point out the possibility of international cooperation in using climate information to avoid potentially worsening conditions during a global energy shortage.

IMPACT OF CLIMATIC VARIATIONS ON ENERGY SYSTEMS

Historically we have seen climate variations on every time and space scale. For example:

- In the United States (2) the November to March heating season of 1976-77 had 22% more heating degree days than the same period of 1975-76. This corresponded to a 1.8°C difference in average temperatures (3).

- Nationally the heating seasons of 1976-79 have had 15% more heating degree days than those of 1973-76 (2).

- In California (4) the rainy seasons of 1975-76 and 1976-77 were 60% drier than the 1931-77 long-term mean.

- In the Mid-Atlantic states (4) the years 1962-66 had 18% less rain than the long-term mean.

- World-wide (5) the five years from 1962 to 1966 were .7°C cooler than the preceding three years.

- In Europe (6) the 1690's were 1.5°C colder than the average temperature for 1580-1790.

- The whole World (7) was cold from 1812 to 1817. During the summer of 1816 frosts were reported every month in New York and New England. During that year, Western Europe had similarly severe weather.

- According to Flohn (8) there may have been a number of abrupt climate events in the last 700,000 years where temperature have dropped 5°C in 50 years over large areas. Such events may occur as often as once every 1,000 to 10,000 years.

Extreme climate events lasting several years seem to occur every decade. One can speculate on the effect a world-wide cold period would have on the international market for petroleum; or how an abrupt temperature decrease of 5°C over a large area would affect the local economy. In this section we will describe two climate events that had a substantial impact on energy systems in the United States.

In 1975-77 a severe drought in the Western United States had a major impact on the economy of that region. Power costs were raised considerably because hydropower had to be replaced by more expensive thermal generation. In California the increased cost was borne primarily by Pacific Gas and Electric (PG&E) customers since the utility is heavily hydropower dependent. In 1977 PG&E's operating expenses were about 30% greater than the 1976 operating expenses of about $1,275 million (9). That year (10) 50 million barrels of oil had to be burned statewide to make up the energy deficit. At the January 1980 world price level this would have increased the U.S. trade deficit by almost $1.5 billion. Ultimately, these costs were passed on to the California consumer.

Farmers in particular were hard hit by the additional energy costs. It is estimated that in a normal year, approximately 85% of the total water demand in California comes from agriculture. With surface water supplies severely restricted in 1977, water allotments to agriculture were reduced by over 60%. Agricultural users attempted to replace this deficit by pumping up more ground water. During 1977, over 6 million acre feet of water were brought to the surface for irrigation purposes.

Ground water is estimated to have accounted for over one-half the water used in California agriculture that year. Statewide the extra energy associated with the additional pumping was approximately 1 billion kilowatt-hours. This expenditure cost California farmers over $25 million (10).

In the Pacific Northwest, part of the expected energy deficiency was reduced by the curtailments of interruptible customers. This resulted in some unemployment, operational shutdowns, and additional costs for purchasing thermal energy. The greatest impacts were in the aluminum industry. The drought ended before the Bonneville Power Administration (BPA) was forced to curtail all its interruptible customers. According to the BPA (9) the total curtailment of all its interruptible customers would have resulted in the following economic impact:

- "370,000 tons per year cut in aluminum production (23.4% of 1,578,000 tons).
- "$355 million added to the nation's foreign trade deficit, if the lost production were replaced by imports.
- "$53 million annually in lost wages in the Pacific Northwest.
- "$21.6 million annually in lost freight payments.
- "$32.3 million lost annually in materials and supplies not purchased.
- "1,900 jobs lost (14.0% of 13,700) in direct Pacific Northwest in the electroprocess industry.
- "6,800 — total of direct and secondary jobs lost in Pacific Northwest."

The effect of a prolonged drought on energy generation alone would cost the Western United States billions of dollars. Resulting increases in the U. S. trade deficit would further weaken the dollar.

While the Western United States suffered energy shortfalls due to drought in 1976-77, the Eastern two-thirds of the country suffered one of the worst winters in history. The protracted period of record setting low temperatures raised the nation's energy bill by $4-8 billion (1). Oil imports had to be increased by about 150 million barrels. The natural gas industry was unprepared for the unpredicted increase in demand, much of their equipment could not operate at these record low temperatures. As a result, there was a natural gas shortage that caused curtailment of supplies to industrial customers and schools. Unemployment (10) caused by the resulting gas curtailments rose from 240,000 in the later part of January to a peak of 1,200,000 on February 4. By the end of

February about 160,000 were still unemployed because of the shortage. Approximately 20 states were affected by the curtailment. Ohio suffered over 45% of the total national shortfall, and New York about 20%. It has been estimated that the federal government may have paid up to $100 million in unemployment benefits (10). Because lost production was probably made up eventually, the true economic impact of this temporary unemployment is hard to estimate.

Congress reacted to the shortages of early-1977 by passing the Natural Gas Policy Act of 1978. This act gave absolute priority for natural gas usage to residential and small commercial customers. This is an example of a political reaction to a climate variation. This legislation will have a significant impact on the natural gas industry, for reasons given below.

Utilities and pipeline companies have high fixed costs. These fixed costs are figured into their rate structure based on normal demand. When severe weather increases demand, revenues are increased faster than total costs, so the companies may earn excess profits; on the other hand, if demand is down they may suffer decreased profits.

Residential and small commercial users of natural gas have been given absolute priority for natural gas use. Supplies to industry and large commercial users must be interrupted to avoid curtailing delivery to homes and small businesses. Since the small users are highly temperature sensitive, they would receive a larger share of the total gas supplies during cold weather. If increased demand were to cause a curtailment of natural gas, a utility with few high priority residential and commercial users might lose substantial revenue, while a neighboring utility with many uninterruptible customers would reap windfall profits. Thus, it would seem incumbent on utilities to raise their proportion of temperature sensitive uninterruptible customers. If such a trend were to develop nation wide, it could eventually have severe consequences if supplies were for some reason to decrease.

Thus, a law intended to ameliorate the impact of climate variations might in the long run enhance this impact. The natural gas policy act is a good example of how climate impacts can affect society by perturbing the political process. It shows the need for careful study before implementing strategies to deal with climate variations or any effort to further regulate the energy market.

In summary, it can be said that recent climate events have cost U.S. citizens billions of dollars for additional energy. They have resulted in increased oil imports, and thus have weakened the dollar and the U.S. economy. They have resulted in a Congressional Act that might actually increase U.S. vulnerability to climate variations. The history of climate variations show us that even larger climate anomalies can be expected in the future. Unless the energy situation improves radically, these anomalies will have important consequences for society.

AMELIORATION OF CLIMATE IMPACTS

Given that the impact of climate variations on the national economy has been large, an important question to ask is whether these impacts could have been ameliorated. The winter of 1976-77 is an example of a case where some simple precautions could have been taken to avoid a major societal disruption (10). There were two major reasons why the increased natural gas demand for that winter could not be met. First, one of the major pipeline companies actually sold its reserves before the January record cold weather. This gas was used by utilities and other industries who could have burned other more abundant supplies such as propane and heating oil. Second, the severe cold dropped the pressure in the natural gas storage areas so low that the companies had insufficient pumping capacity to retrieve the stored gas. Had the pipeline companies not sold off their reserves early in the winter and had more pumping capacity been available, much of the anxiety caused the nation could have been avoided.

In the aftermath of the national trauma caused by the January-February 1977 natural gas shortage, the utilities and pipeline companies have been adequately prepared for extremely cold winters. The heating season of 1976-77 had 11% more population weighted heating degree days (HDD) than normal. The heating season of 1977-78 was nearly as severe. It had 10% more degree days than normal. Yet there were virtually no shortages or weather produced unemployment. Clearly, American industry had the resources to deal with unusually cold winters, it was simply unprepared in 1976-77.

There was evidence to suggest that such cold weather was possible. While the cold weather suffered by the Eastern half of the country in October-January of 1976-77 was unusual, it was not unprecedented (12). Virtually all of the excess HDD's occurred in October through January. February was normal and March was above normal. October-January of 1917-18 and 1836-37 were about as cold as 1976-77. While January of 1977 set records in many places; sites with very long temperature records show that the Januarys of 1856 and 1857 were about as cold (12). Unfortunately, this information is still not generally available to the utility industry.

There was, however, at least one report published prior to 1976-77 suggesting that a winter as cold as 1976-77 was possible. In 1974, a report (13) to the Energy Policy Office of the President was made based on the 1931-73 temperature record. It stated that years with a 10% increase in HDD's would occur about every 100 years. Thus, weather conditions as extreme as 1976-77 were known to occur once every hundred years. Once the natural gas industry experienced these conditions, there were prepared for them the next year. Energy system planners should examine the cost and benefits of being prepared for such adverse conditions, decide how prepared they should be, and then take long-term action to carry out their decisions.

The winter of 1976-77 is an extreme example of why climate variability should be taken account in managing energy systems. Gordon McKay of the Canadian Climate Center and John Page of the University of Sheffield have discussed other cases at this workshop. Another good example is the concern in the Western United States about the probability of the recurrence of a drought as severe as that of 1975-77. If such a drought is likely to recur, then these states must consider reexamining their policies on growth of water use. At the present time, ground water is being pumped out of the Central Valley of California water table faster than it is replaced. Unless the water table is allowed to recover, it will take larger and larger amounts of energy to pump this water. If a severe drought were to occur during an energy shortage it would be difficult and expensive to pump adequate water for irrigation.

The situation in the upper Colorado River Basin is even more critical. It is widely believed that water supplies are already over-committed in this area. A boom in energy development will put further stress on supplies. Hopefully, it will not take a disastrous drought to make people aware of the need to be prepared for climate variations.

So far we have stressed the need for defining the likelihood of extreme climate events, and of building or retrofitting systems to be prepared for such events. Of course accurate long-range forecasts would be extremely useful. Again the winter of 1976-77 is a good example. During that winter, cold temperatures were experienced unusually early. On some systems gas was being withdrawn from underground storage during the fall, a time of year when gas is typically being injected. About 12% of the nation's inventory of stored gas was consumed during November; the previous November almost no gas was withdrawn from storage. Had it been known in November that December would be very cold many large industrial customers would have been switched to alternative fuels, and the stored natural gas would have been conserved. This would have considerably reduced the level of curtailments necessary in January and February. The curtailments could also have been further reduced had it been known that March would be unusually warm (14).

It is interesting to note that in late November of 1976, several of the long-range forecasters most respected by professional meteorologists predicted a switch from warm to cold weather for the Eastern United States (14). One even stated that it would be the coldest winter in 20 years. Unfortunately, past experience has shown that present day forecasts have very limited skill so a special effort by the climatological community to put the nation on alert for cold weather would not have been unjustified. Until such time as long-range forecasting is substantially improved, the best strategy for ameliorating climate impacts is to build systems which can respond to extreme events in a flexible manner.

PROSPECTS FOR THE FUTURE

In this paper we have given a few examples of how better use of information about climate variations can improve the management of energy systems. There is a rising concern both in private industry and in governmental regulatory and information offices about the potentially disruptive effect extreme variations in the climate can have on energy and therefore on the economy and society. Energy managers and analysts agree that:

1. Present methods for relating climate variations to energy use or disruption of energy supply are not sufficiently accurate; the economic and societal effects of adverse weather are largely unknown.

2. The improvement of monthly and seasonal forecasts would be of help in the allocation of scarce fuels.

3. Data on past climate variations are not available on a timely basis or in the most useful formats; the formats of presently available forecasts could be improved.

4. Methods of using presently available climate data and forecasts could be greatly improved.

5. The climate effects of the various energy technologies are largely unknown.

As part of the United States Climate Program a multi-agency interdisciplinary program is being instituted to minimize the impact of climate on energy and energy on climate. The following projects are now being initiated; they are listed in order of priority:

1. Detailed data are being gathered on energy usage and supply; they are being correlated with weather data down to the county level. This will help resolve many of the uncertainties about the impact of climate variations.

2. Economic studies are being made about the effect of climate variations on industry and the consumer, particularly the poor and aged. Implications about societal impacts will be drawn from these studies.

3. These impact studies will serve as the basis for programs that will develop systems less vulnerable to climate variations from both a financial and engineering point of view; the studies will also aid in making better use of climate information.

4. Data bases of energy related climate variables, such as heating degree days, are being developed; they will contain

both forecasts and observations and will be available on a real-time basis to concerned parties.

5. Specific efforts will be made to improve climate forecasts of variables critical to energy systems.

6. More intense investigations of the effects of energy on climate will be made.

These programs require the cooperation of energy experts, climatologists, economists, decision analysts, and many other physical and social scientists. Communication between these groups has already begun. The United States Department of Energy will be primarily responsible for the impact and engineering studies; to perform these studies it will need input on the type of climate variations to be expected in the future, particularly extreme events. It is expected that NOAA, NSF, and NASA will attempt to devise improved climate forecast methods.

While the national efforts mentioned above will give a good start on climate impact assessment, the problem is ultimately an international one. Energy is scarce and expensive world-wide. There are international agreements on how much oil each consuming nation should import. However, if a nation has an exceptionally cold winter it may need more oil. Global weather patterns (15) are such that it is quite common for the eastern two-thirds of the United States, Europe, Korea and Japan all to have cold weather at the same time. When this happens, dry conditions in the Western United States are also likely. An extreme version of this pattern occurred in 1976-77. These weather conditions caused an increase of over one million barrels per day in U. S. imports (2,3). We have no data on how much non-U. S. imports changed, but they probably increased as well. Since only about 30 million barrels a day is available for import world-wide, this was a substantial increase in demand. The last two oil supply crises have involved shortfalls of only a few percent. If such a climate extreme were to occur when there was a crude oil shortfall, it would make a bad situation worse. The winter of 1976-77 is just one example of a climate event that could have adverse consequences for the international economy.

As climatologists we can make a contribution to society by making both national and international institutions aware of the likelihood of extreme climate events. An important aspect of the U. S. Department of Energy Climate Program has been to encourage climatologists to work with energy planners and managers to propose strategies for ameliorating climate impacts. An international effort would be needed to determine the frequency of world-wide adverse climate events and determine their effect on global energy demand. Monitoring of world-wide temperature and precipitation data could provide early warning that world-wide energy consumption is unusually high. Use of such information could help alleviate the adverse impacts of climate extremes on the global economy.

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